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Invited Perspective: Polyaromatic Hydrocarbons in Alcohol—An Unappreciated Carcinogenic Mechanism?

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Polycyclic aromatic hydrocarbons (PAHs) are a large class of organic compounds produced by the incomplete combustion of fossil fuels as well as from high heat applied to organic matter such as tobacco, meat, and grain.[1] As such, PAHs are implicated in cancers associated with diverse occupations, smoking, and consumption of processed and cooked meat.[1,2] Among the most well-known PAHs is benzo(a)pyrene (BaP), one of the causes of scrotal cancer in chimney sweeps[2] and thus one of the first occupational exposures linked to cancer risk.[3] A thought-provoking review appearing in this issue of *Environmental Health Perspectives* by King et al.[3] summarizes a modest and longstanding, but neglected, literature on PAHs in alcohol that suggests these chemicals could also play a role in alcohol-induced carcinogenesis.

Anybody who has ever eaten barbecued burnt ends, had grilled hot dogs at the ballpark, or enjoyed a peaty single malt scotch from Islay understands the appeal of rich, smoky flavors typically associated with cooking over flames or high heat and the resulting production of PAHs. However, processed meats[2] and alcoholic beverages[4] are designated as group 1 carcinogens by the International Agency for Research on Cancer (IARC), and the World Cancer Research Fund and American Institute of Cancer Research recommend limiting consumption of red and processed meats.[5] Given what we know about the origins of PAHs and their solubility in ethanol, perhaps it should not come as a surprise that they have been found in alcoholic beverages aged in charred barrels, flavored with peat smoke, or made with roasted grains.

As summarized by King et al.,[3] PAHs—including BaP—have been examined in 11 English-language papers covering some 124 different varieties of spirits, wine, and beer, a small subset of alcoholic beverage brands.[6] BaP equivalents up to 93 ng/L (in rum) were reported, with some values exceeding exposure limits for BaP in drinking water of the United Kingdom and Australia (both at 10 ng/L) and Canada (40 ng/L), but not the United States (200 ng/L). Five of the studies did not sum measured PAHs but reported high levels of specific PAHs such as 8,862 ng/L of three-ring PAHs in Laphroaig scotch and 4,991 ng/L of two-ring PAHs in Virginia Gentleman bourbon, with lower levels of four-, five-, and six-ring compounds.[7] Unfortunately, these studies used different analytical techniques and were published over many years (1966–2019). Additional work surveying a wide range of alcohol products and using up-to-date analytical approaches[8] would be worthwhile to better understand exposure to PAHs from alcohol.

BaP is the only PAH designated a group 1 carcinogen by the IARC, but several mixtures of PAHs and PAH-producing industries are also judged to be group 1 carcinogens.[1,9] Of the 60 individual PAHs reviewed by IARC, three others are classified as probably carcinogenic and 11 as possibly carcinogenic.[10,11] Inadequate data are available to classify the 45 remaining compounds.[11] Sixteen PAHs have been designated priority pollutants by the US Environmental Protection Agency. A key problem for such designation is the fact that virtually all exposures to PAHs involve mixtures of many different PAHs. This makes exposure assessment and estimates of risk complex and difficult. Yet, increased understanding of exposure pathways, such as through alcohol consumption, and application of new developments in epidemiological analysis of exposure mixtures could advance our understanding of the roles of specific PAHs and PAH mixtures.[12–14]

Despite the fact that levels of BaP and PAHs in some alcohol samples exceeded established thresholds for drinking water, readers may well wonder if drinking alcoholic beverages would result in meaningful exposures. We note that over 2 billion people drink alcohol,[15] and consumption cuts across all ages, genders, and race/ethnicities, with evidence for greater harms for individuals at lower income levels.[16] Even small increases in risk, when so many are exposed, is a matter of concern. Alcohol consumption has long been recognized as increasing the risk of cancer at multiple sites, but research on the underlying mechanisms have largely focused on pathways related to acetaldehyde, a metabolic product of ethanol, as well as direct effects of ethanol on metabolism, hormone levels, and inflammation.[17] Modeling the potential contribution of PAHs to alcohol-induced carcinogenesis could be a useful next step. Systems models of tobacco exposure and lung cancer demonstrate the utility of such approaches for exploring mortality outcomes, interactions between risk factors, and alternative policy scenarios.[18]

The presence of known carcinogens in commonly consumed alcoholic beverages raises several further questions of interest for public health. For example, traditional methods of barrel charring and the intensity of such charring used to produce Spanish brandies influence their concentrations of PAHs.[19] Interestingly, another popular (but nonalcoholic) beverage, yerba mate, also contains PAHs, which may contribute to its association with esophageal squamous cell carcinoma.[20,21] Because regulating methods of preparing traditional and often beloved food and drink is fraught with challenges, an alternative approach involves labeling on containers or at the point of sale. There is already some precedent for doing so; labels concerning cancer risk related to alcohol are mandated in a few

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countries,[22,23] point-of-sale warnings concerning alcohol and cancer are required in California,[24] and efforts are under way to include such labels on alcohol containers in the United States.[25] Such labels are effective at increasing awareness and reducing consumption but receive substantial industry opposition.[26] An alternative to warnings about health effects involves labeling with ingredients, like that required for prepared foods in the United States. This is complicated by the presence of numerous secondary compounds derived from plants, products of processes used to make specific alcohol beverages such as the aforementioned aging in charred barrels, and a large but poorly known set of additives related to flavor, aroma, mouthfeel, and other factors. Further research on alcohol labeling could help address these issues.[27]

As well as being a drug, a social lubricant, a component of gastronomic enjoyment, and a prominent part of history and culture, alcohol is also a feature of a large landscape of what are being called "commercial determinants of health."[28] These diverse roles for alcohol create a myriad of complexities concerning research and practice aimed at reducing its negative health effects. Nevertheless, such efforts are vital, and the review by King et al.[3] should stimulate further efforts to better understand potential health effects of PAHs in alcoholic beverages and to address alcohol and public health in all its complexity.

References

1. Straif K, Baan R, Grosse Y, Secretan B, El Ghissassi F, Cogliano V. 2005. Carcinogenicity of polycyclic aromatic hydrocarbons. Lancet Oncol 6(12):931–932, https://doi.org/10.1016/S1470-2045(05)70458-7.
2. Bouvard V, Loomis D, Guyton KZ, Grosse Y, Ghissassi FE, Benbrahim-Tallaa L, et al. 2015. Carcinogenicity of consumption of red and processed meat. Lancet Oncol 16(16):1599–1600, PMID: 26514947, https://doi.org/10.1016/S1470-2045(15)00444-1.
3. King L, Aplin R, Gill C, Naimi T. 2024. A state-of-the-science review of alcoholic beverages and polycyclic aromatic hydrocarbons. Environ Health Perspect 132(1):016001, https://doi.org/10.1289/EHP13506.
4. Baan R, Straif K, Grosse Y, Secretan B, El Ghissassi F, Bouvard V, et al. 2007. Carcinogenicity of alcoholic beverages. Lancet Oncol 8(4):292–293, PMID: 17431955, https://doi.org/10.1016/s1470-2045(07)70099-2.
5. WCRF (World Cancer Research Fund International). *Limit Red and Processed Meat*. London UK: WCRF. https://www.wcrf.org/diet-activity-and-cancer/cancer-prevention-recommendations/limit-red-and-processed-meat/ [accessed 11 December 2023].
6. BevNET. 2024. *BevNET Beverage Brands Database*. https://www.bevnet.com/brands [accessed 4 December 2023].
7. Kleinjans JC, Moonen EJ, Dallinga JW, Albering HJ, van den Bogaard AE, van Schooten FJ. 1996. Polycyclic aromatic hydrocarbons in whiskies. Lancet 348(9043):1731, PMID: 8973440, https://doi.org/10.1016/S0140-6736(96)24051-6.
8. Wise SA, Sander LC, Schantz MM. 2015. Analytical methods for determination of polycyclic aromatic hydrocarbons (PAHs) — a historical perspective on the 16 U.S. EPA priority pollutant PAHs. Polycyclic Aromatic Compounds 35(2–4):187–247, https://doi.org/10.1080/10406638.2014.970291.
9. Baan R, Grosse Y, Straif K, Secretan B, El Ghissassi F, Bouvard V, et al. 2009. A review of human carcinogens—part F: chemical agents and related occupations. Lancet Oncol 10(12):1143–1144, PMID: 19998521, https://doi.org/10.1016/s1470-2045(09)70358-4.
10. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. 2010. Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. IARC Monogr Eval Carcinog Risks Hum 92:1–853, PMID: 21141735.
11. IARC (International Agency for Research on Cancer). 2019. *Tumour Site Concordance and Mechanisms of Carcinogenesis*. Lyon, France: IARC.
12. Bobb JF, Valeri L, Claus Henn B, Christiani DC, Wright RO, Mazumdar M, et al. 2015. Bayesian kernel machine regression for estimating the health effects of multi-pollutant mixtures. Biostatistics 16(3):493–508, PMID: 25532525, https://doi.org/10.1093/biostatistics/kxu058.
13. Czarnota J, Gennings C, Wheeler DC. 2015. Assessment of weighted quantile sum regression for modeling chemical mixtures and cancer risk. Cancer Inform 14(Suppl 2):159–171, PMID: 26005323, https://doi.org/10.4137/CIN.S17295.
14. Keil AP, Buckley JP, O'Brien KM, Ferguson KK, Zhao S, White AJ. 2020. A quantile-based g-computation approach to addressing the effects of exposure mixtures. Environ Health Perspect 128(4):47004, PMID: 32255670, https://doi.org/10.1289/EHP5838.
15. WHO (World Health Organization). 2018. *Global Status Report on Alcohol and Health 2018*. Geneva, Switzerland: WHO.
16. Probst C, Kilian C, Sanchez S, Lange S, Rehm J. 2020. The role of alcohol use and drinking patterns in socioeconomic inequalities in mortality: a systematic review. Lancet Public Health 5(6):e324–e332, PMID: 32504585, https://doi.org/10.1016/S2468-2667(20)30052-9.
17. Rumgay H, Murphy N, Ferrari P, Soerjomataram I. 2021. Alcohol and cancer: epidemiology and biological mechanisms. Nutrients 13(9):3173, PMID: 34579050, https://doi.org/10.3390/nu13093173.
18. Levy DT, Cummings KM, Heckman BW, Li Y, Yuan Z, Smith TT, et al. 2021. The public health gains had cigarette companies chosen to sell very low nicotine cigarettes. Nicotine Tob Res 23(3):438–446, PMID: 32710538, https://doi.org/10.1093/ntr/ntaa128.
19. García-Falcón MS, Simal-Gándara J. 2005. Determination of polycyclic aromatic hydrocarbons in alcoholic drinks and the identification of their potential sources. Food Addit Contam 22(9):791–797, PMID: 16192065, https://doi.org/10.1080/02652030500198498.
20. Kamangar F, Schantz MM, Abnet CC, Fagundes RB, Dawsey SM. 2008. High levels of carcinogenic polycyclic aromatic hydrocarbons in mate drinks. Cancer Epidemiol Biomarkers Prev 17(5):1262–1268, PMID: 18483349, https://doi.org/10.1158/1055-9965.EPI-08-0025.
21. Oranuba E, Deng H, Peng J, Dawsey SM, Kamangar F. 2019. Polycyclic aromatic hydrocarbons as a potential source of carcinogenicity of mate. J Environ Sci Health C Environ Carcinog Ecotoxicol Rev 37(1):26–41, PMID: 30596334, https://doi.org/10.1080/10590501.2019.1555323.
22. Stockwell T, Solomon R, O'Brien P, Vallance K, Hobin E. 2020. Cancer warning labels on alcohol containers: a consumer's right to know, a government's responsibility to inform, and an industry's power to thwart. J Stud Alcohol Drugs 81(2):284–292, PMID: 32359059.
23. The Lancet Gastroenterology & Hepatology. 2023. Distilling the message: Irish plans for alcohol warning labels. Lancet Gastroenterol Hepatol 8(3):199, PMID: 36773608, https://doi.org/10.1016/s2468-1253(23)00014-6.
24. Budenz A, Moser RP, Eck R, Agurs-Collins T, McNeel TS, Klein WMP, et al. 2022. Awareness of alcohol and cancer risk and the California proposition 65 warning sign updates: a natural experiment. Int J Environ Res Public Health 19(19):11862, PMID: 36231178, https://doi.org/10.3390/ijerph191911862.
25. Consumer Federation of America. 2023. *Consumer, Public Health Groups Petition for Cancer Warning on Alcohol*. https://consumerfed.org/testimonial/consumer-public-health-groups-petition-for-cancer-warning-on-alcohol/ [accessed 4 December 2023].
26. Zhao J, Stockwell T, Vallance K, Hobin E. 2020. The effects of alcohol warning labels on population alcohol consumption: an interrupted time series analysis of alcohol sales in Yukon, Canada. J Stud Alcohol Drugs 81(2):225–237, PMID: 32359054.
27. Gapstur SM, Bandera EV, Jernigan DH, LoConte NK, Southwell BG, Vasiliou V, et al. 2022. Alcohol and cancer: existing knowledge and evidence gaps across the cancer continuum. Cancer Epidemiol Biomarkers Prev 31(1):5–10, PMID: 34728469, https://doi.org/10.1158/1055-9965.EPI-21-0934.
28. Maani N, Petticrew M, Galea S. 2022. *The Commercial Determinants of Health*. Oxford, UK: Oxford University Press.